Package ‘allanvar’

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Type Package

Title Allan Variance Analysis

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Description A collection of tools for stochastic sensor error characterization using the Allan Variance technique originally developed by D. Allan.

License GPL-2

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`allanvar` *Allan Variance Package*

Description

Set of function to compute the Allan Variance of sensor output in order to perform sensor characterization of the most dominant stochastic errors underlying the signal.

Details

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Version:	1.1
Date:	2015-07-07
License:	GPL-2
LazyLoad:	yes

The Allan Variance method was developed by David Allan in 1966. Allan proposed a simple variance analysis method for the study of oscillator stability (Allan 1966). After that this method has been adopted by the inertial sensor community for the simplicity of the technique in comparatively to others techniques like the power spectral density in the frequency domain or the autocorrelation function. The Allan variance can provide directly information on the types and magnitude of various noise terms. Since the analogies to inertial sensors, this method has been adapted to random drift characterization of inertial sensors.In the 80's was publishes the first paper related to the use if the Allan variance with inertial sensors (Kochakian 1980). In 1983 Tehrani gave out the detailed deviation about the Allan variance noise terms expression from their rate noise power spectral density for the ring laser gyro (Tehrani 1983). In 2003, the Allan variance method was first applied in Micro Electrical Mechanical Sensor (MEMS) noise identification (Haiying and El-Sheimy 2003) (El-Sheimy et. al. 2008) and is presented as a standard recommendation for IEEE (Institute of Electrical and Electronics Engineers, Inc.) since 1997 (IEEE Std 952-1997).

Following the Annex C in the IEEE recommendation (IEEE Std 952-1997), a number of specific noise terms can be identified using the Allan variance. Those noise terms are known to exist in inertial sensors. In this package the Allan Variance technique is developed in R in order to easilly identified the dominant stochastic noise processes. Since the Allan variance technique is a graphic method based on ploting the Allan standard deviation against the cluster time a plot utility is also available in this package.

To summarize, `Alla Variance Packages` provides with a set of functions to compute the Allan variance. The identification of the noise terms in the Allan variance is performed in a $log-log$ graph of the Allan deviation against the cluster time τ. Then, the package provides with a function `plotav` to visualize the results in a $log - log$ graph. Afterwards, simple analyses are needed to calculate the noise coefficients. The reader can find abundant information in the literature concerning noise characterization using the Allan variance technique.

Author(s)

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References

Allan, D. W. (1966) *Statistics of Atomic Frequency Standards* Proceedings of IEEE, vol. 54, no. 2, pp. 221-230, Feb, 1966.

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Papoulis, A and Unnikrisha,S (2002) *Probability, Random Variables and Stochastic Processes* Fourth Edition. McGraw-Hill Series in Electrical and Computer Engineering.

Tehrani, M. M. (1983) *Ring Laser Gyro Data Analysis with Cluster Sampling Technique* Proceedings of SPIE, vol. 412

Examples

```
#This example is also available under
#the command: demo(allanvar)

#Loading values
data(gyroz)

#Allan variance computation using avar
avgyroz <- avar(gyroz@.Data, frequency(gyroz))

#Allan variance computation using avarn
avngyroz <- avarn(gyroz@.Data, frequency(gyroz))

#Allan variance computation using avari
#Simple integration of the angular velocity
igyroz <- cumsum(gyroz@.Data * (1/frequency(gyroz)))
igyroz <- ts (igyroz, start=c(igyroz[1]), delta=(1/frequency(gyroz)))
```

```
avigyroz <- avari(igyroz@.Data, frequency(igyroz))

#Ploting all
plot (avgyroz$time,sqrt(avgyroz$av),log= "xy", xaxt="n" , yaxt="n", type="l",
        col="blue", xlab="", ylab="")
lines (avngyroz$time,sqrt(avngyroz$av), col="green", lwd=1)
lines (avigyroz$time,sqrt(avigyroz$av), col="red")
axis(1, c(0.001, 0.01, 0.1, 0, 1, 10, 100, 1000, 10000, 100000))
axis(2, c(0.00001, 0.0001, 0.001, 0.01, 0.1, 0, 1, 10, 100, 1000, 10000))
grid(equilogs=TRUE, lwd=1, col="orange")
title(main = "Allan variance Analysis Comparison", xlab = "Cluster Times
        (Sec)", ylab = "Allan Standard Deviation (rad/s)")

legend(10, 4e-03, c("GyroZ (avar)", "GyroZ(avarn)", "GyroZ(avari)"),  fill =
        c("blue", "green", "red"))
```

---

avar *Allan Variance (cluster size as a power of 2).*

Description

The function avar computes the Allan Variance of a set of values with a given constant sampling frequency. The input has to be the output rate/acceleration from the sensors. In this version of the Allan variance computation the number and size of cluster has been computed as a power of 2 n=2^l, l=1,2,3,...(Allan 1987) which is convenient to estimate the amplitude of different noise components.

Usage

```
avar(values, freq)
```

Arguments

values	Calibrated sensor output (i.e: angular velocity or acceleration)
freq	Sampling frequency rate in Hertz

Details

Considering a number N of outputs from the sensor at a constant time interval of t_0. n groups of consecutive data points could be formed $(n < N/2)$, each member of the groups is a cluster. Associated with each cluster is a time τ, which is equal $t_0, 2t_0, 3t_0 \ldots nt_0$. Taking the instantaneous output of the inertial sensors (i.e. angular velocity) here denoted by $\Omega(t)$, the cluster average is:

$$\bar{\Omega}_k(\tau) = 1/\tau \int_{t_k}^{t_{k+1}} \Omega(t)dt$$

Where $\bar{\Omega}(t)$ represents the cluster average value of the output rate for a cluster which starts from the kth data point and contains n data points depending on the length of τ. The definition of the subsequent cluster average is as following, where $t_{k+1} = t_k + \tau$

$$\bar{\Omega}_{k+1}(\tau) = 1/\tau \int_{t_{k+1}}^{t_{k+1}+\tau} \Omega(t)dt$$

The interesting value for the Allan variance analysis is the difference for each of two adjacent clusters.

$$\varepsilon_{k+1,k} = \bar{\Omega}_{k+1}(\tau) - \bar{\Omega}_k(\tau)$$

For each cluster of time τ, the ensemble of defined of the previous formula forms a set of random variables. The important information is the variance of ε_s over all the clusters of the same size that can be formed from the entire data. Then the Alla Variance of the length τ, is defined as

$$\theta^2(\tau) = 1/(2(N-2n)) \sum_{k=1}^{N-2n} [\bar{\Omega}_{k+1}(t) - \bar{\Omega}_k(t)]^2$$

Obviously, for any finite number of data points (N), a finite numbers of cluster of a fixed length (τ) can be formed. Hence $\theta^2(\tau)$ represents an estimation of the real variance. The quality of estimate depends on the number of independent clusters of a fixed length that can be formed. Defining the parameters as the percentage error in estimating the Allan standard deviation of the cluster due to the finiteness of the number of clusters gives

$$\zeta_{AV} = (\sigma(\tau, M) - \sigma(\tau))/(\sigma(\tau))$$

where $\sigma(\tau, M)$ denotes the estimate of the Allan standard deviation obtained from M independent clusters, $\sigma(\tau, M)$ approaches its theoretical value $\sigma(\tau)$ in the limit of M approaching infinity. A lengthy and straightforward calculation shows the percentage error, the formula has been used in the error of the estimation of the Allan Variance and it is equal to :

$$\sigma(\zeta_{AV}) = 1/(\sqrt{2(N/n-1)})$$

Where N is the total number of data points in the entire data set and n is the number of data points contained in the cluster. The equation shows that the error of the estimation is short when the length of the cluster is small as the number of independent cluster performed is large.

Characterization of stochastic errors requires identifying its PSD function. There is a unique relationship between the Allan variance (time-domain) and the PSD (frequency-domain) of the random process defined by

$$\sigma^2(\tau) = 4 \int_0^{\infty} S_\Omega(f)(\sin^4(\pi f \tau))/((\pi f \tau)^2)df$$

Where $S_\Omega(f)$ is the two-side PSD of the random process.

Value

Return an object of class `data.frame` containing the Allan Variance computation with the following fields:

`time`	Value of the cluster time.
`av`	The Allan variance value: variance among clusters of same size.
`error`	Error on the estimation: Uncertainty of the value.

Author(s)

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References

Allan, D. W. (1966) *Statistics of Atomic Frequency Standards* Proceedings of IEEE, vol. 54, no. 2, pp. 221-230, Feb, 1966.

IEEE Std 952-1997 *IEEE Standard Specification Format Guide and Test Procedure for Single Axis Interferometric Fiber Optic Gyros*.

Papoulis, A and Unnikrisha,S (2002) *Probability, Random Variables and Stochastic Processes* Fourth Edition. McGraw Hill Series in electrical and Computer Engineering.

Examples

```
#Load data
data(gyroz)

#Allan variance computation using avar
avgyroz <- avar(gyroz@.Data, frequency(gyroz))
plotav(avgyroz)
abline(1.0+log(avgyroz$time[1]), -1/2, col="green", lwd=4, lty=10)
abline(1.0+log(avgyroz$time[1]), 1/2, col="green", lwd=4, lty=10)
legend(0.11, 1e-03, c("Random Walk"))
legend(25, 1e-03, c("Rate Random Walk"))
```

---

avari *Allan Variance (from integrated values).*

Description

The function `avari` computes the Allan Variance of a set of values with a given constant sampling frequency. The diferent with `avar` function is that the input values are the integral value of sensor output (i.e: rate/acceleration). That means angle from gyros and velocity from accelerometers. In this version of the Allan variance computation the number and size of cluster n has been computed as in `avar` function $n = 2^l, l = 1, 2, \ldots$(Allan 1987).

Usage

```
avari(values, freq)
```

Arguments

`values`	Integration of the calibrated sensor output (i.e: angel or velocity)
`freq`	Sampling frequency rate in Hertz

Details

The Allan variance can also be defined either in terms of the output rate as defined in `avar` by $\Omega(t)$ or using the output angle/velocity as this function does. Defining:

$$\theta(t) = \int^{t} \Omega(t^{'})dt^{'}$$

The lower integration limit is not specified as only angle differences are employed in the definition. Angle measurement are made at discrete times given by $t = nt_0, n = 1, 2, \ldots, N$. The notation is simplify by writing $\theta_k = \theta(kt_0)$. The cluster average is now defined as:

$\bar{\Omega}_k(\tau) = (\theta_{k+n} - \theta_k)/\tau$ and $\bar{\Omega}_{k+1}(\tau) = (\theta_{k+2n} - \theta_{k+n})/(\tau)$

The equivalent Allan Variance estimation is defined as:

$$\theta^2(\tau) = 1/(2\tau^2(N-2n)) \sum_{k=1}^{N-2n} [\theta_{k+2n} - 2\theta_{k+n} + \theta_k]^2$$

Value

Return an object of class `data.frame` containing the Allan Variance computation with the following fields:

`time`	Value of the cluster time.
`av`	The Allan variance value: variance among clusters of same size.
`error`	Error on the estimation: Uncertainty of the value.

Author(s)

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References

Allan, D. W. (1966) *Statistics of Atomic Frequency Standards* Proceedings of IEEE, vol. 54, no. 2, pp. 221-230, Feb, 1966.

IEEE Std 952-1997 *IEEE Standard Specification Format Guide and Test Procedure for Single Axis Interferometric Fiber Optic Gyros*.

El-Sheimy, N.; Haiying Hou.; Xiaoji, Niu (2008) *Analysis and Modeling of Inertial Sensors Using Allan Variance* IEEE Transaction on Instrumentation and Measurement.

Examples

```
#Load data
data(gyroz)

#Allan variance computation using avari
#Simple integration of the angular velocity
igyroz <- cumsum(gyroz@.Data * (1/frequency(gyroz)))
igyroz <- ts (igyroz, start=c(igyroz[1]), delta=(1/frequency(gyroz)))
avigyroz <- avari(igyroz@.Data, frequency(igyroz))
plotav(avigyroz)
abline(1.0+log(avigyroz$time[1]), -1/2, col="green", lwd=4, lty=10)
abline(1.0+log(avigyroz$time[1]), 1/2, col="green", lwd=4, lty=10)
legend(0.11, 1e-03, c("Random Walk"))
legend(25, 1e-03, c("Rate Random Walk"))
```

---

avarn *Allan Variance (incremental cluster size by unit).*

Description

The function avarn computes the Allan Variance of a set of values with a given constant sampling frequency. The input has to be the output rate/acceleration from the sensors. In this version of the Allan variance computation the number and size of cluster n has been computed as the maximum number of cluster into N recorded values, which is ceil [(N-1)/2].

Usage

```
avarn(values, freq)
```

Arguments

values	Calibrated sensor output (i.e: angular velocity or acceleration)
freq	Sampling frequency rate in Hertz

Details

It computes the Allan variance in the same way that avar function. The difference is that the number of cluster time and size are selected as the maximum number of cluster into N recorded values. However, Papoulis et.al recommend to estimate the amplitude of different noise components defined as in avar function. Therefore is recommended to use the avar in most of the cases, considering also computational cost.

Value

Return an object of class `data.frame` containing the Allan Variance computation with the following fields:

`time`	Value of the cluster time.
`av`	The Allan variance value: variance among clusters of same size.
`error`	Error on the estimation: Uncertainty of the value.

Author(s)

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References

Allan, D. W. (1966) *Statistics of Atomic Frequency Standards* Proceedings of IEEE, vol. 54, no. 2, pp. 221-230, Feb, 1966.

IEEE Std 952-1997 *IEEE Standard Specification Format Guide and Test Procedure for Single Axis Interferometric Fiber Optic Gyros.*

Papoulis, A and Unnikrisha,S (2002) *Probability, Random Variables and Stochastic Processes* Fourth Edition. McGraw Hill Series in electrical and Computer Engineering.

Examples

```
#Load data
data(gyroz)

#Allan variance computation using avarn
avngyroz <- avarn(gyroz@.Data, frequency(gyroz))
plotav(avngyroz)
abline(1.0+log(avngyroz$time[1]), -1/2, col="green", lwd=4, lty=10)
abline(1.0+log(avngyroz$time[1]), 1/2, col="green", lwd=4, lty=10)
legend(0.11, 1e-03, c("Random Walk"))
legend(25, 1e-03, c("Rate Random Walk"))
```

`gyroz` *Gyro sensor output for one-axis simulated gyroscope*

Description

This dataset is an object of class "ts" (time series) with sensor output at a specifid frequency.

Usage

```
data(gyroz)
```

Source

Simulated gyro using R software. It is not from a real sensor but it has a clear Random Walk and Rate Random Walk with a small dataset.

Examples

```
data(gyroz)
frequency(gyroz)
plot(gyroz)
```

---

plotav — *Allan Variance plot*

Description

This function plot the Allan variance graph. That is the Allan deviation $\sigma(\tau)$ against the cluster time τ

Usage

```
plotav(avdf)
```

Arguments

avdf	`data.frame` with the results after calculating the Allan variance using `avar`, `avarn` or `avari`

Details

`plotav` has been developed in order to plot the Allan variance estimation in an easy way but for sure other plot functions and stronger R graphics capabilities could also be used in order to visualize the slopes.

Value

Allan variance plot: Log-Log plot of the standard deviation $\sigma(\tau)$ against the cluster times.

Author(s)

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References

IEEE Std 952-1997 *IEEE Standard Specification Format Guide and Test Procedure for Single Axis Interferometric Fiber Optic Gyros*.

Examples

```
#Load data
data(gyroz)

#Allan variance computation using avar
avgyroz <- avar(gyroz@.Data, frequency(gyroz))
plotav(avgyroz)
```

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